



Europäisches Patentamt

European Patent Office

Office européen des brevets



⑪ Publication number:

0 462 599 A2

⑫

EUROPEAN PATENT APPLICATION

⑬ Application number: 91110089.9

⑮ Int. Cl. 5: G01B 11/06

⑭ Date of filing: 19.06.91

⑯ Priority: 19.06.90 US 540660

Palo Alto, CA 94306(US)

Inventor: de Geus, Richard

6721 John Drive

Cupertino, CA 95014(US)

Inventor: Ebbing, Peter

847 Riverside Drive

Los Altos, CA 94024(US)

⑰ Date of publication of application:

27.12.91 Bulletin 91/52

⑲ Designated Contracting States:

DE FR GB IT NL

⑳ Applicant: APPLIED MATERIALS, INC.

3050 Bowers Avenue

Santa Clara California 95054(US)

⑳ Representative: DIEHL GLAESER HILTL & PARTNER

Patentanwälte Flüggenstrasse 13

W-8000 München 19(DE)

㉑ Inventor: Struij, Bruno

2633 Waverly Street

㉒ Apparatus and method for etch rate monitoring.

㉓ An etch rate monitor for use with semiconductor wafer etching processes includes a source of light (28) of normal incidence to the wafer surface through a window (26) in the etching chamber (10). In a first embodiment, a Fresnel or positive lens (36) is used to collect some of the diffraction orders caused by the repetitive patterns on the wafer surface (18, 20) which merge from the window (26). In alternate embodiments, a concave spherical mirror and/or a photodetector system are used to collect the diffraction orders. A collimating lens (42) applies these diffraction orders of normal incidence to interference filters (40) which reject plasma and ambient light and pass the diffraction orders to a photodetector (38) to monitor etch rate as a function of the cycle period between interference minima or maxima caused by the difference in path length between the etched and not etched surfaces of the wafer.

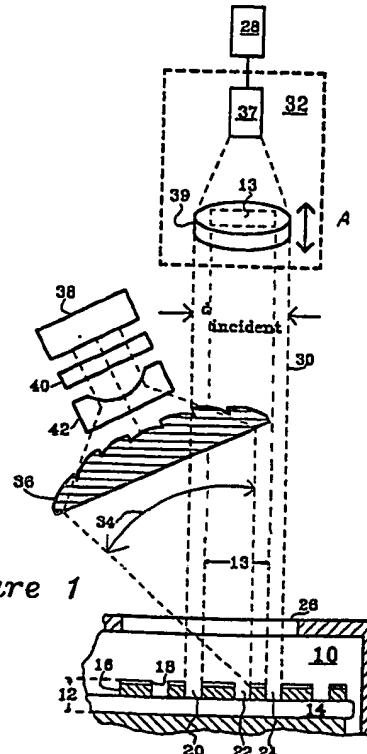


Figure 1

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This invention relates to techniques for monitoring etch rate on semiconductor or other wafers during processing in an etch chamber and especially to an etch rate monitor.

Conventional approaches to etch rate monitoring for semiconductor wafers during processing illuminate the repetitive patterns on the wafers through windows into the etch chambers and use photodetector devices to monitor changes in diffraction patterns from repetitive features. Such conventional devices are extremely pattern dependent and therefore relatively complicated to setup, maintain and use. Such conventional devices are quite sensitive to alignment, do not provide satisfactory penetration deep into small features and have poor signal to noise ratio because only a few diffraction orders are collected and processed.

The preceding and other shortcomings of the prior art are addressed and overcome by the present invention that provides an etch rate monitor for wafer processing, according to independent claim 1 and a method of monitoring the etch rate according to independent claim 9. Further advantageous features and details of the invention are evident from the dependent claims, the description and the drawings. The claims are intended to be understood as a first non-limiting approach of defining the invention in general terms.

The invention therefore provides an etch rate monitor for wafer processing, having means for applying a collimated light beam of normal incidence to the surface of a masked wafer in an etch chamber, means for collecting light diffracted therefrom, and means for monitoring the etch rate in the chamber in accordance with the time varying intensity of the collected light.

In another aspect, the present invention provides a method for monitoring etch rate during wafer processing by applying a collimated light beam of normal incidence to the surface of a masked wafer being processed, collecting light diffracted therefrom and monitoring the etch rate in accordance with the time varying intensity of the collected light.

These and other features and advantages of this invention will become further apparent from the detailed description that follows which is accompanied by a set of drawing figures. In the figures and description, numerals indicate the various features of the invention, like numerals referring to like features throughout both the drawings and the description.

Fig. 1 is an illustration of a portion of an etch chamber and an etch rate monitor associated therewith in accordance with the present invention in which a lens system is used for collecting diffraction orders.

Fig. 2 is an illustration of a portion to be etched

of the semiconductor wafer shown in **Fig. 1**.

Fig. 3 is an illustration of another embodiment of the present invention in which a concave mirror is used for collecting diffraction orders.

Fig. 4 is an illustration of another embodiment of the present invention in which a photodetector is used directly for collecting diffraction orders.

Fig. 1 is an illustration of a portion of etch chamber 10 including semiconductor wafer 12. There are many etching processes in which different materials are etched or protected by resist or mask or resist-mask, but the following description will serve as a common example thereof in order to properly describe the present invention.

Semiconductor wafer 12 is formed of silicon crystal base 14 on which is grown a layer of material, such as silicon dioxide 16, to be etched during processing in etch chamber 10. A pattern of etch resistant material, such as resist pattern 18, is formed in a desired, repetitive masking pattern on a layer to be etched, such as silicon dioxide layer 16. The repetitions of the masking pattern represent portions of semiconductor wafer 12 to be separated in a subsequent process into separate semiconductor dies, such as die 13. During operation of etch chamber 10, an etching process, not shown, is used to etch away and remove portions of silicon dioxide layer 16, such as portions 20, 22 and 24, which are not protected by resist pattern 18. The system can also be used for monitoring the etch rate of other wafer processes including single crystal and recessed polysilicon processes.

An important operating consideration during this etching process is the depth of the etch. Although great care and planning goes into attempting to predetermine the total etching depth required to remove exactly the amount of material desired to be removed, it is still very important to actually monitor the depth of the etch to stop the etching process at the proper time for the wafer being processed to provide a good yield of properly etched wafers.

Etch chamber 10 includes window 26 through which the etching processes may be viewed. In accordance with the present invention, light source 28 provides incident collimated light beam 30 whose diameter, d_{incident} is preferably slightly larger than the largest dimension of die 13. If, for example, die 13 is a rectangular die, d_{incident} should be only slightly larger than the diagonal dimension of die 13 in order not to compete with the collection of the diffraction orders emerging from window 26.

That is, as d_{incident} is increased in diameter, the opening, not shown, through collection optics 36 through which d_{incident} must pass must be increased. This results in a reduction of the useful area of collection optics 36 and therefore a reduc-

tion in the diffraction orders which may be collected thereby.

Light source 28, and associated light source optics 32, are mounted with respect to etch chamber 10 so that collimated light beam 30 passes through the opening in collection optics 36 discussed above and is of normal incidence to the surface of semiconductor wafer 12. Incident collimated light beam 30 preferably enters window 26 close to its perimeter in order to maximize the collection of diffraction orders.

Light source optics 32 includes stressed fiber beam homogenizer 37 positioned between light source 28, which may conveniently be an optical laser, and variable focal length collimating lens 39 so that the light in incident collimated light beam 30 may be made as uniform as possible. The diameter of incident collimated light beam 30 may be adjusted by moving variable focal length collimating lens 39 with respect to stressed fiber beam homogenizer 37 as indicated by arrow A.

Repetitive resist pattern 18 serves as a diffraction grating and reflects many diffraction orders as a result of incident collimated light beam 30. Many diffraction orders emerge from window 26. Several such diffraction orders emerge through window 26 along reflection path 34 to collection optics 36 as will be discussed below with reference to Fig. 2. Semiconductor wafer 12 should be positioned as close as possible to window 26 to allow at least one quadrant of the diffraction orders to emerge from window 26.

Collection optics 36 is a large diameter, short focal length lens, such as a Fresnel lens or a positive lens, not shown, in order to collect as many diffraction orders as possible. The positive lens would provide better quality diffracted light to detector 38 than a Fresnel lens which tends to scatter light because of its construction. The positive lens however, would have to be very thick and therefore both heavy and cumbersome. In addition, the very thickness of the lens would result in partial attenuation of absorbed light. The Fresnel lens is thinner and easier to work with, but the resultant light scattering may not be acceptable for some applications. Alternate embodiments are shown in Figs 3 and 4, below, which reduce these problems.

Collection optics 36 includes a hole or other opening for permitting incident collimated light beam 30 to reach semiconductor wafer 12 without obstruction. Collection optics 36 serves to redirect diffraction orders emerging along reflection path 34 to detector 38, positioned along the optical axis of collection optics 36. Detector 38 may be conventional photodetection apparatus and is used, with electronic systems not shown, for monitoring etch rate in etch chamber 10.

During operation, the etch rate, R , may be determined by monitoring the intensity of the collected portion of the light diffracted by resist pattern 18. This intensity varies in a repeating pattern as a function of etching depth. As will be discussed in greater detail below with reference to Fig. 2, the light intensity varies from a maxima to a minima every time the depth of the etch, called feature depth d , increases by one half wavelength of incident light.

With reference now to Fig. 2, collimated light beam 30 is of normal incidence to resist pattern 18. The etching process causes etched surface 35 of silicon dioxide layer 16, to be etched away and recede further and further below the surface of resist pattern 18. Etching therefore increases the length of the path from light source 28 to etched surface 35, represented by ray 33. The path length of light source 28 to pattern 18 is represented by ray 31 and will not change as a result of the etching process. The length of ray 33 will therefore exceed the length of ray 31 by feature depth d .

When the path length difference between ray 31 and ray 33 is equal to odd multiples of half the wavelength of incident collimated light beam 30, these rays will reach detector 38 180° out of phase with each other and destructively interfere. Destructive interference results in a detectable reduction of intensity as monitored by detector 38. When the path length difference between ray 31 and ray 33 is equal to even multiples of half the wavelength of incident collimated light beam 30, these rays will reach detector 38 exactly in phase with each other and constructively interfere. Constructive interference results in a detectably greater light intensity than destructive interference as monitored by detector 38.

The intensity monitored by detector 38 therefore exhibits maxima and minima resulting from constructive and destructive interference every time feature depth d changes by Δd , an amount of etch depth equal to one half wavelength of the incident light, λ , as follows:

$$\Delta d = \lambda / 2.$$

Etch rate R is the rate of change of feature depth d as a function of time and may be determined by monitoring cycle period T , the time between occurrences of light intensity maxima or minima, as determined by detector 38. Each cycle period T represents a change of depth equal to one half wavelength of incident collimated light beam 30. It may be convenient, for example, to monitor the cycle period T between light intensity minima. Etch rate R may then be determined from the wavelength of incident collimated light beam 30

and cycle period T , as follows:

$$R = \Delta d / T = \lambda / 2 T.$$

Improvements in the accuracy of the etch rate monitoring information determined by detector 38 can be achieved by the inclusion of interference filter 40 between collection optics 36 and detector 38 to reject plasma light, ambient light and other sources of light which add noise and reduce monitoring accuracy. Interference filter 40 requires the light beam to be of normal incidence. For this purpose, collimating lens 42 is placed between collection optics 36 and interference filter 40. Collimating lens 42 may conveniently be a plano-concave lens with a negative focal point.

In addition, it is desirable to select light source 28 so that the smallest convenient wavelength light may be used in order to most easily monitor the smallest possible change in feature depth.

Fig. 3 is an illustration of an etch rate monitor in accordance with the present invention in which reflective optical system, such as concave spherical mirror 44, is used in lieu of collection optics 36, shown in Fig. 1, to converge the diffracted light from semiconductor wafer 12 onto collimating lens 42, interference filters 40 and detector 38. Concave mirror 44 is provided with an opening, not shown, which permits unobstructed passage of incident collimated light beam 30 from light source optics 32 through window 26 to semiconductor wafer 12. Spherical concave mirror 44 provides the same quality of light collection as a positive lens used as collection optics 36 as shown in Fig. 1 and substantially superior quality of light collection than a Fresnel lens would under the same circumstances.

In addition, concave mirror 44 does not have the attenuation and losses associated with a very thick positive lens, nor the weight. Because concave mirror 44 permits the diffraction orders to be redirected by reflection to collimating lens 42, interference filters 40 and detector 38, these devices may be mounted closer to etch chamber 10 making the resultant device more compact and enclosable.

Fig. 4 is an illustration of still another embodiment of an etch rate monitor in accordance with the present invention in which photodetector 46 is used in lieu of collection optics 36, shown in Fig. 1, or concave mirror 44, shown in Fig. 3, to collect and detect the diffracted light from semiconductor wafer 12. Interference filters 40 may conveniently be positioned between photodetector 46 and window 26.

Heat transfer requirements for photodetector 46 and/or etch chamber 10 may be conveniently handled by positioning heat exchanger 48 in the sur-

face of photodetector 46 opposite interference filters 40. Heat exchanger 48 may be a liquid cooled heat exchanger ensuring consistent performance of photodetector 46 and be provided with coolant in flow port 50 and out flow port 52.

Photodetector 46, and heat exchanger 48, must be provided with an opening, not shown, which permits unobstructed passage of incident collimated light beam 30 from light source optics 32 through window 26 to semiconductor wafer 12. Interference filters 40 permit passage of light with the wavelengths in incident collimated light beam 30 and reject light with wavelengths different therefrom so that an opening within interference filters 40 for passage of incident collimated light beam 30 is not required.

Photodetector 46 may be a single photodetector or an array of such photodetectors, depending upon the application. The advantages of photodetector 46 over concave mirror 44 shown in Fig. 2 or collection optics 36 shown in Fig. 1 are simplicity, compactness and convenience. In order to improve the diffraction order collection capability of photodetector 46, it may be desirable to mount photodetector 46 at some predetermined angle, rotated about an axis such as axis 47, so that diffraction orders may be detected more normal to the surface of photodetector 46.

30 Claims

1. An etch rate monitor for wafer processing, comprising:
 - 35 means (28, 30) for applying a collimated light beam (30) of normal incidence to the surface of a masked wafer (18, 20) in an etch chamber (10);
 - 40 means (36, 44, 46) for collecting light diffracted from the wafer surface; and
 - 45 means (38, 46) responsive to the time varying intensity of the collected light for monitoring etch rate in the chamber (10).
2. The etch rate monitor claimed in claim 1, wherein the means (36) for collecting the diffracted light comprises:
 - 50 a large diameter, short focal length collecting lens (36), which preferably comprises a Fresnel lens.
- 55 3. The etch rate monitor claimed in claim 1, wherein the means for collecting the diffracted light comprises:

a concave spherical mirror (44).

4. The etch rate monitor claimed in claim 1 wherein the means for collecting the diffracted light comprises:

5 a photodetector assembly (46).

5. The etch rate monitor claimed in claim 4 wherein the means for collecting diffracted light further comprises:

10 a heat exchanger (48) associated with the photodetector assembly (46).

15 6. The etch rate monitor claimed in one of the preceding claims wherein the means for collecting further comprises:

means for rejecting light with wavelengths substantially different from the wavelength of the collimated light beam, which means are preferably positioned between the collecting lens or the spherical mirror and the detecting means.

20 7. The etch rate monitor claimed in claim 6 wherein the means for rejecting interfering light comprises:

25 an interference filter (40); and

30 a collimating lens (42) for applying light from the collecting lens to the interference filter.

35 8. The etch rate monitor claimed in one of the preceding claims wherein the means responsive to the time varying light intensity determines the cycle period between intensity minima or intensity maxima.

40 9. The etch rate monitor claimed in one of the preceding claims, wherein the means responsive to the time varying light intensity determines etch rate as a function of the wavelength (X) of the incident light and the cycle period (T) between interference patterns of the diffracted light.

45 10. A method of monitoring etch rate during semiconductor wafer processing, comprising the steps of:

50 applying a collimated light beam of normal incidence to the surface of a masked wafer being processed;

55 collecting diffracted light therefrom; and

detecting changes in diffracted light intensity to monitor etch rate in the chamber.

11. The method of monitoring etch rate claimed in claim 10, wherein the diffracted light collection step further comprises:

collecting the diffracting light with a large diameter, short focal length collecting lens, which preferably is a Fresnel lens.

12. The method of monitoring etch rate claimed in claim 10, wherein the step of collecting the diffracted light uses a reflective optical system.

13. The method of monitoring etch rate claimed in claim 10, wherein the step of collecting the diffracted light uses a photodetector assembly.

14. The etch rate monitor claimed in claim 13, wherein the step of collecting diffracted light further comprises:

associating a heat exchanger with the photodetector assembly.

15. The method of monitoring etch rate claimed in one of claims 10 to 14, wherein the step of collecting diffracted light further comprises:

rejecting light with wavelengths substantially different from the wavelength of the collimated light beam.

16. The method of monitoring etch rate claimed in claim 15 wherein the step of rejecting interfering light further comprises:

collimating the light from the collecting lens; and

applying the collimated light to interference filtering.

17. The method of monitoring etch rate claimed in one of claims 10 to 16, wherein the detecting step further comprises the step of:

determining the cycle period between intensity minima or maxima.

18. The method of monitoring etch rate in one of claims 10 to 17, wherein the detecting step further comprises the step of:

determining the etch rate as a function of the wavelength of the incident light and the cycle period between interference patterns of the

diffracted light.

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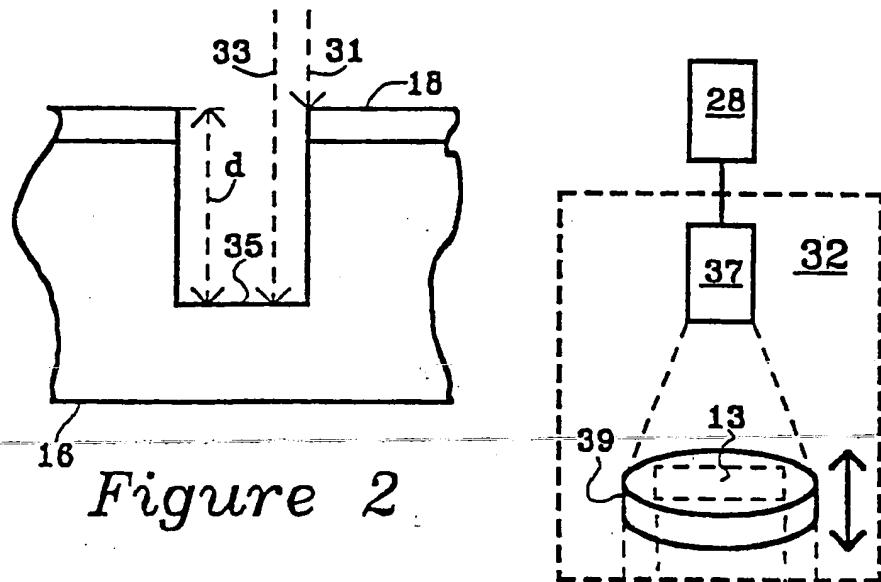


Figure 2

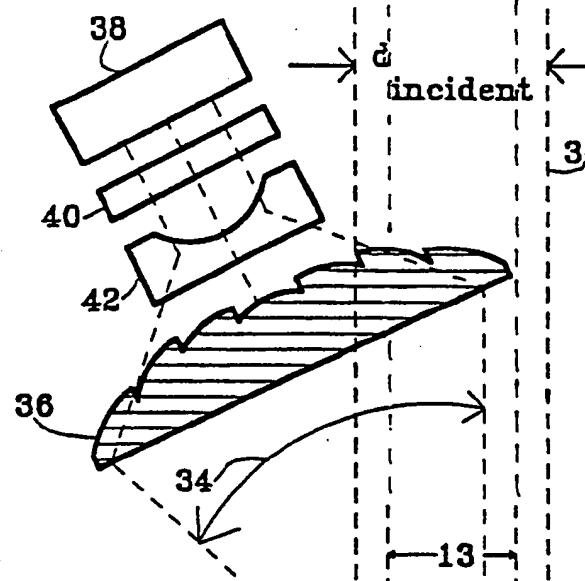
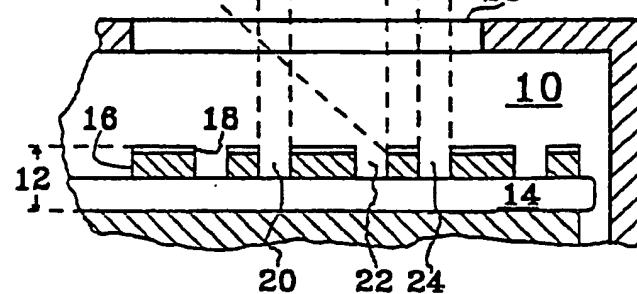


Figure 1



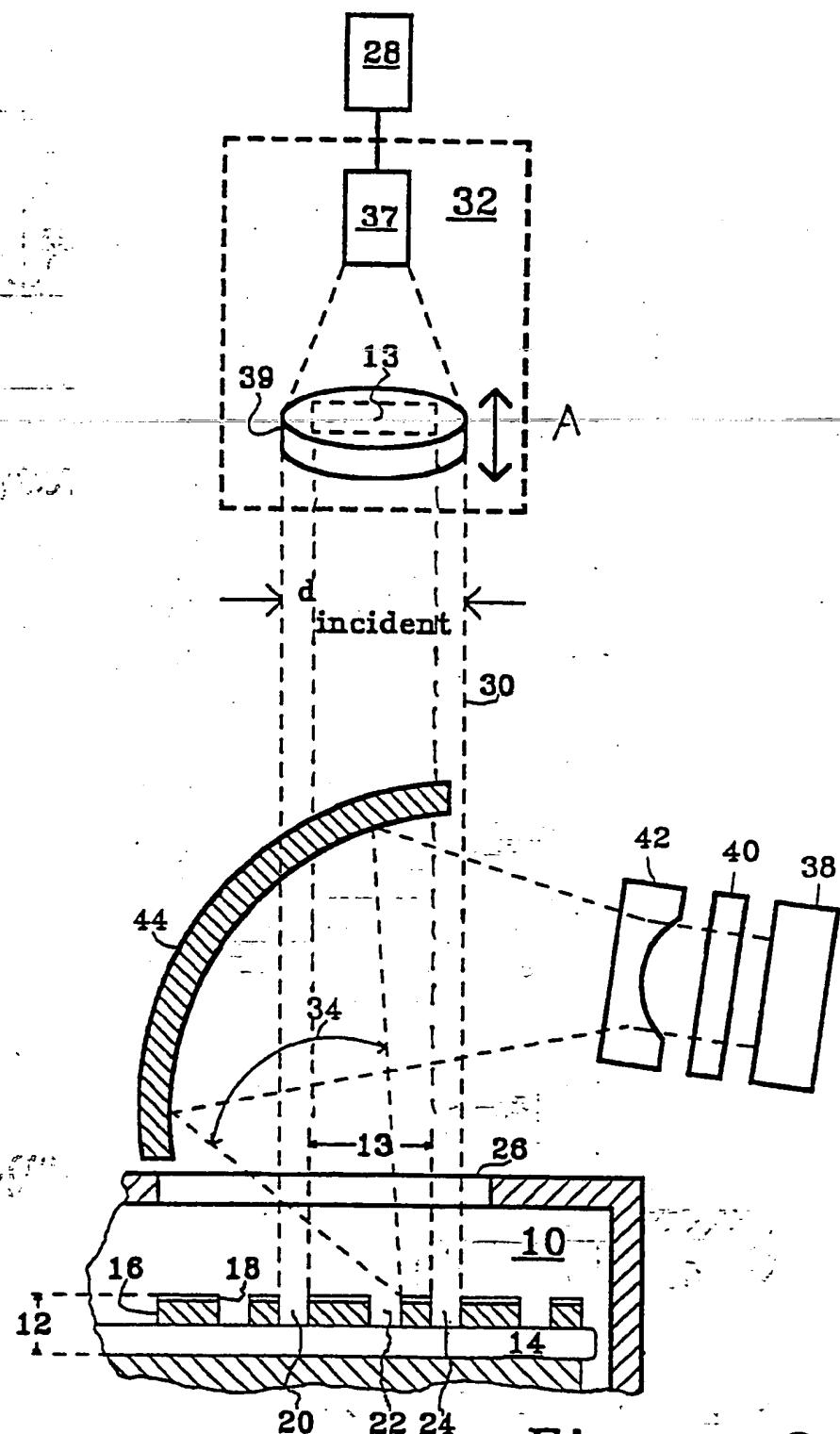


Figure 3

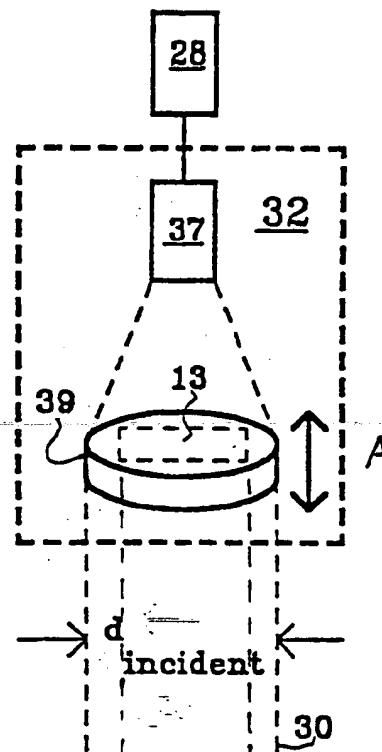
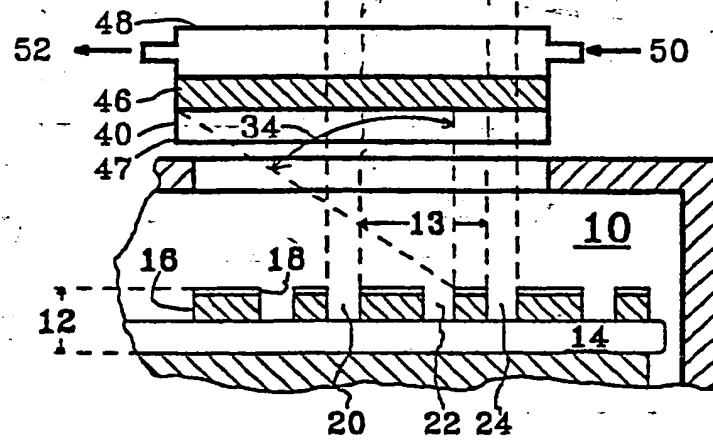
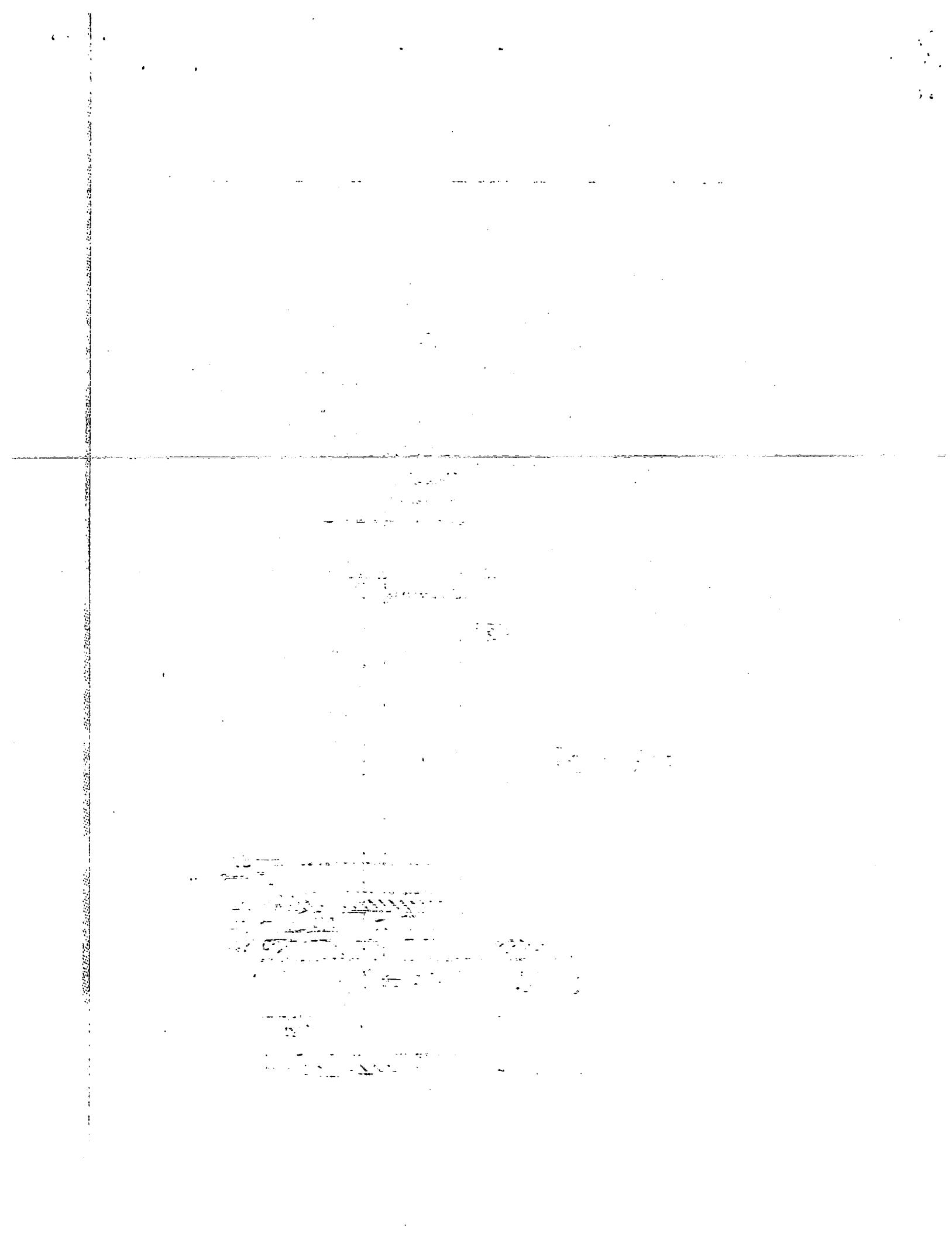


Figure 4







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⑪ Publication number:

0 462 599 A3

⑫

EUROPEAN PATENT APPLICATION

⑬ Application number: 91110089.9

⑮ Int. Cl. 5: G01B 11/06

⑭ Date of filing: 19.06.91

⑯ Priority: 19.06.90 US 540660

⑰ Inventor: Strul, Bruno
2633 Waverly Street
Palo Alto, CA 94306(US)
Inventor: de Geus, Richard

⑰ Date of publication of application:
27.12.91 Bulletin 91/52

6721 John Drive
Cupertino, CA 95014(US)
Inventor: Ebbing, Peter
847 Riverside Drive
Los Altos, CA 94024(US)

⑯ Designated Contracting States:
DE FR GB IT NL

⑰ Representative: DIEHL GLAESER HILTL &
PARTNER
Patentanwälte Flüggenstrasse 13
W-8000 München 19(DE)

⑰ Date of deferred publication of the search report:
12.08.92 Bulletin 92/33

⑰ Applicant: APPLIED MATERIALS, INC.
3050 Bowers Avenue
Santa Clara California 95054(US)

⑯ Apparatus and method for etch rate monitoring.

⑯ An etch rate monitor for use with semiconductor wafer etching processes includes a source of light (28) of normal incidence to the wafer surface through a window (26) in the etching chamber (10). In a first embodiment, a Fresnel or positive lens (36) is used to collect some of the diffraction orders caused by the repetitive patterns on the wafer surface (18, 20) which merge from the window (26). In alternate embodiments, a concave spherical mirror and/or a photodetector system are used to collect the diffraction orders. A collimating lens (42) applies these diffraction orders of normal incidence to interference filters (40) which reject plasma and ambient light and pass the diffraction orders to a photodetector (38) to monitor etch rate as a function of the cycle period between interference minima or maxima caused by the difference in path length between the etched and not etched surfaces of the wafer.

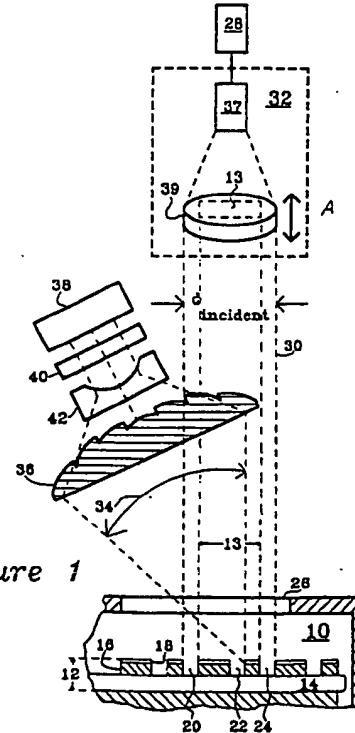


Figure 1

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European Patent
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EUROPEAN SEARCH REPORT

Application Number

EP 91 11 0089

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. CL.5)
Y	EP-A-0 352 740 (APPLIED MATERIALS INC.) * the whole document *	1,2,4, 6-13, 15-18	G01B11/06
Y	PATENT ABSTRACTS OF JAPAN vol. 11, no. 088 (E-490) 18 March 1987 & JP-A-61 241 923 (HITACHI LTD) 28 October 1986 * abstract *	1,2,4, 6-13, 15-18	
Y	US-A-4 873 430 (ANTHONY JULIANA) * column 2, line 50 - column 3, line 66 *	1,3,4,6, 7,10,12, 13,15,16	
Y	PATENT ABSTRACTS OF JAPAN vol. 10, no. 008 (E-373) 14 January 1986 & JP-A-60 173 837 (NIPON DENSHIN DENMIA KOSHA) 7 September 1985 * abstract *	1,3,4,6, 7,10,12, 13,15,16	TECHNICAL FIELDS SEARCHED (Int. CL.5)
			G01B
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
THE HAGUE		11 JUNE 1992	PANDOLFI C.
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